MILITARY APPLICATIONS OF CIRCADIAN RHYTHM PRINCIPLES

Kent S. Hull

Decision Science Consortium, Inc.

Reston, VA

FINAL DRAFT

This contractor document was prepared for the OTA report entitled *Biological Rhythms and Shift Work*. It is being made available because it contains much useful information beyond that used in the OTA report. However, it is not endorsed by OTA, nor has it been reviewed by the Technology Assessment Board. References to it should cite the contractor, not OTA, as the author.

May 18, 1990

J752-79

CONTENTS

Glossary of Abbreviations and Terms v

Summary and Scope..... 1

Summary 1

General 1

Scope 2

Military Operations Affected by Biological Rhythm Disruptions 2

Military Tasks Requiring 24 Hour Manning ... 4

Avoiding or Minimizing Performance Disruption 5

Use of Technical Information and Research Results 6

Disruptions to Biological Rhythms 8

Transient Disruptions 8

Acute Fatigue 8

Chronic Fatigue 8

Chronic Perturbations to Biological Rhythms 8

Maladaptations to Biological Rhythm Disruptions 9

Stress Interactions 9

Environmental Stressors Increasing the Effects of Circadian Disruptions 11

Kinds of Operations 12
Steady Routine 12
Relocate-to-Steady Routine 13
Relocate-to-Surge 13
Steady Routine-to-Surge 13
Surge-to-Steady Routine 14

Military Operations Involving Circadian Disruptions .. 17
General: Training and Readiness Exercises 17
Army Operations 17
Deployment 17
Reinforcement 18
Special Operations 19
Air Force Operations 19
Strategic Forces 19
Tactical and Transport Forces 20
Support Units 20
Navy Operations 21
Routine Deployment 21
Short-Notice Deployment 22
Independent Operations 22
Submarines 23
Surface Combatants 24
Aircraft Carriers 25
Amphibious Force Ships 28
Logistic Support (Supply) Ships 29
Marine Corps Operations 29

Amphibious Assault 30

Military Tasks Involving Circadian Disruptions 32

Combat and Forward Deployment Work Week 32

Kinds of Tasks 33

Physical 33

Equipment Preparation and Maintenance 34

Equipment Operation 35

Vehicle Control 35

Vigilance 37

Command 38

Tasks With Civil Sector Equivalents 39

Regulations and Guidance on Mediating Circadian Disruptions 39

Planning Factors 39

Guidance 41

Flight Crews 42

Command 42

Guidance for Wartime Operations 42

Circadian Disruption-Induced Performance Decrements and Intervention Strategies 47

Experience With Performance Decrements 47

Army 47

Air Force 48

Navy 48

Marine Corps 49

Performance Decrements, Consequences, and
Mediation/Intervention 51
Physical Tasks 51
Equipment Preparation and Maintenance 52
Equipment Operation 53
Vehicle Control 54
Vigilance 56
Command 59
Research and Technology Prospects 63
Research 63
General Character 63
Completed 65
Current 66
Technology: Ways To Use Research Results 66
Practical Needs and Potential Gains 66
Technology Implementation Methods 68

References 71

GLOSSARY OF ABBREVIATIONS AND TERMS

ABBREVIATIONS

ARI: Army Research Institute for the Behavioral and Social Sciences. Manages Army research and development in psychology, human factors, manpower, personnel & training, etc.; has field offices at most major Army installations.

ARO: Army Research Office. Manages Army basic and applied research in the physical sciences.

AFOSR: Air Force Office of Scientific Research. Manages Air Force basic and applied research.

ICBM: Intercontinental ballistic missile. A nuclear warhead-carrying strategic weapon.

ONR: Office of Naval Research. Manages all Navy basic and applied research, in OCNR.

ONT: Office of Naval Technology. Manages all Navy exploratory development, in OCNR.

OCNR: Office of the Chief of Naval Research

ORE: Operational Readiness Exercise/Evaluation. A realistic test of all missions at some higher level of unit aggregation, such as a Navy Battle Group, Air Force Wing, or Army Division.

SAC: Strategic Air Command. The major division of the U. S. Air Force that operates intercontinental bombers and ballistic missiles.

SAD: Seasonal Affective Disorder. Behavioral changes (usually

lethargy, depression, carbohydrate craving) some people experience during short daylight period seasons (winter) at high latitudes.

SOF: Special Operations Forces. A joint (multi-service) command that specializes in unconventional operations. The command was formed after the failed Iranian hostage rescue attempt, to provide standing forces with the equipment, training and capability to succeed in that kind of operation.

USA: United States Army

USAF: United States Air Force

USN: United States Navy

USMC: United States Marine Corps. Part of the U. S. Department of the Navy, under the Secretary of the Navy but not under the Chief of Naval Operations. Subject to Navy directives except where its own are substituted.

TERMS

absolute limiting factors: Limited by human performance capacity.

acute degradation: Occurring over a short period of time.

air defense: Systems and units to detect enemy aircraft and missiles which may attack, and weapons to prevent successful attack.

air defense radar: Radar designed to detect airborne targets for the air defense mission.

Air Force strategic forces (ICBM) operations: Training, exercises, and other activity by crews who man the ICBM

silos.

air support operations (logistic): Air transport of men and materiel as needed in the course of combat operations.

air support operations (tactical): Use of armed aircraft in support of ground combat. Contrasts with strategic air support, which is used to strike against enemy industry, domestic transportation, or population.

all-up exercises: Nothing is simulated, except possibly for some munitions (small arms fire, artillery, etc.)

amphibious operations area: The shore and adjacent sea and land areas that are the scene of an amphibious landing. Ships carrying Marines and their support assemble in the sea area, and Marines and equipment are moved across the shoreline to objectives (points and areas they will control) inland.

antisubmarine warfare: Operations (usually defensive) against hostile submarines. It is the primary mission of "attack" submarines, a major mission of all surface combatants, and of specialized aircraft. Almost all submarine detection is acoustic (sonars and other listening devices); homing torpedoes are used by all antisubmarine units against submarines.

armor: Collective term meaning units and types of vehicles (mostly tanks) that can withstand direct hits from small arms and some larger weapons.

assault force: The collection of ground and support units able to attack an opposing force. Often refers to a Marine landing force.

assault: An attack by ground forces against opposing ground forces.

attack submarines: Submarines with weapons for attacking other submarines and surface ships, and not equipped with nuclear warhead ballistic missiles.

austere simulations: Trainers or exercises which omit many features of the task environment. Single personal computer - based simulations, part-task trainers, and battle exercises where only the communications are represented ("CPX") are examples.

battle group: A Navy striking force, organized around an aircraft carrier. It will usually include air defense ships, antisubmarine ships, some supply ships ("replenishment ships") and often an attack submarine or two.

battle stations manned: Each person aboard a combatant ship is assigned a battle station. If his normally assigned job is related to weapons or sensor operation, the battle station will be the same as the normal work station. Battle stations are manned when "general quarters" is declared.

berthing: Sleeping facilities aboard ship.

berths: The beds and lockers that constitute berthing.

billets (filled): A billet is a position or job in a unit. When a unit is authorized (created on paper), it is first assigned (authorized) billets, which are all the positions necessary to perform the unit mission. When the unit is established, some fraction of its authorized billets are filled by assigning persons to fill them.

boat: Something carried by a ship, or a vessel that does not carry boats.

boat operation: The act of steering or manually controlling a boat; in the case of ships, the state of having the assigned boats performing tasks.

boilers or main engines: Aboard ship, boilers provide the steam to drive the main engines that provide propulsive power. Auxiliary engines provide electrical power and other services; evaporators provide fresh water and the feed water for the boilers.

cavalry: Army units organized around the use of light armed vehicles, usually for reconnaissance and security missions.

chemical agent protective clothing and equipment: Coveralls, gloves, hoods and masks made of materials which will protect the wearer against nerve gas and other agents of chemical warfare. Because they must cover every part of the wearer, they are clumsy and get very hot.

circadian disruption (acute): Short-term disassociation between the work-sleep cycle and the day-night cycle, either by a change to the day-night cycle (transmeridian travel), change to a different work-sleep cycle (lack of sleep or change to a different cycle) or both.

circadian disruption (chronic): Continuing disassociation between the work-sleep cycle and the day-night cycle, usually by a work-sleep cycle different in length from 24 hours.

combat arms personnel: Army personnel whose job involves operation of weapons. Infantry, Artillery, Armor, and Cavalry

are combat arms.

combat cargo: Munitions and other supplies used in combat.

combatants: Parties directly involved in fighting.

command and control decision making: Organized direction of forces by commanders, who respond to changes in conditions by changes in tasking to the forces commanded.

command/combat direction: The actual control of weapons or weapons systems, as by an air controller directing an interceptor aircraft, or a commander on the scene directing the action against a submarine contact.

commanders: Persons authorized, trained, and equipped to direct others in an organized group (a squad, ship system, group of aircraft, *etc.*) in combat.

communications suites: A collection of radios, usually housed in a trailer, truck, or portable building, that supports necessary communications between units served.

continuous flight operations: For a carrier, having aircraft airborne continuously.

continuous operations: Operations that continue 42 hours per day, but which permit sufficient rest to individuals that they can continue indefinitely.

crews: The personnel who man a unit such as a ship, aircraft, artillery piece, *etc.*

defensive operations: Self-protection or ground-holding operations.

degradation in judgement: Making decisions, assessments, or choices that are inappropriate or incorrect. A fatigue

effect.

demolition device: An explosive device that is placed by hand at or near the object or facility it is intended to destroy.

deployment: Movement of a unit (or group of units) to a place where an assigned mission is to be performed. Battle group units deploy from east coast homeports to the Mediterranean Sea.

deployment, regular or routine: Scheduled replacement of a group of units in an overseas area by another.

deployment, surge: Short notice reinforcement of overseas forces by moving additional units there; short notice deployment of Navy units in response to some need for show of force.

doctrinal development: Study and exercises to articulate and test concepts for the use of various kinds of forces in various circumstances.

dog watch: A short watch used to change watch rotation (the change in commencement time of successive watches by a particular watchstander) without changing the numbers of groups of watchstanders (watchstander sections) or the duration of the standard watch.

duty-rest cycle: The period and schedule from commencement of work to the next commencement of work, including a period for sleep and other personal needs.

electronic surveillance: Watching an area with radio receivers that can pick up and identify the likely sources and direction of radar and communications transmissions.

embarked: In a ship but not part of its crew. Marines embark in

amphibious ships.

end strength: The total number in each pay grade authorized by Congress for each service at the end of the year.

equipment casualties: Malfunctions or damage reducing the capability of equipment or rendering it inoperative.

expeditionary: Refers to movement of a force (organized group of ground combat and supporting units) to a new place. This contrasts with forces in place (already there) and reinforcement (moving additional units to augment forces already in place).

expeditionary airfield: A quickly-built airfield (usually from metal matting) for expeditionary operations.

extended operations: Combat activities that continue for some time.

fatigue: Lack of performance reserve. The result of extended work without rest.

fire-and-maneuver: The basic actions of ground combat forces.

forces in place: At the onset of hostilities, those already there.

full-scale combat exercises: Training involving all of the kinds of units that would be involved in actual combat, generally in an area where realistic maneuver (repositioning for tactical effect) can be conducted.

full-scale flight operations: From a carrier, operating surveillance, defensive, and offensive missions.

garbled or incorrect operations orders: An operation order gives a unit instructions on what to do, when. A garbled order is

either incomprehensible or is somehow mixed up, with the effect that the unit directed is not effective in coordination or support with other units.

general quarters: The condition aboard ship where all personnel are at battle stations and all systems are at maximum readiness for combat.

high alert conditions for strategic forces: These are "alert" conditions, either for training or national defense. Intercontinental nuclear weapons are made more ready for launch.

high operations tempo: Continued frequent combat actions (maneuvers, relocations, flights, firings, etc.)

high-readiness operations of strategic forces: Same as high alert conditions; in the case of bombers, moving them to forward locations or keeping crews near their aircraft.

individual effectiveness: Capability to perform assigned tasks effectively.

land combat: Fighting between forces on land (including air support, etc.

major exercises: Operational Readiness Evaluations, National Exercises, major fleet exercises. These involve large numbers of units under realistic conditions. National Exercises involve allied forces.

manned air wings: An air wing is composed of a number of squadrons (usually nine in a carrier air wing), each of which is manned by flight crews, maintenance, and support personnel.

manned carriers: An aircraft carrier has a crew of several thousand, and embarks an air wing with several thousand more personnel.

manned (equipment): Manning equipment means having persons at or on it to operate it.

manned (units): Manning units means assigning personnel to them.

manning-wartime: This is the manning level (numbers of billets filled)to support the tempo of operations anticipated in wartime. Peacetime manning authorization (the most people a unit can expect to have in peacetime) may be expressed as a fraction of wartime manning.

manpower planning factors: The methods and assumptions used to decide appropriate peacetime and wartime manning.

Marine Corps combined arms: Integration of ground (infantry, light armor and artillery) and air forces (close sir support and transport). It amounts to a doctrine that is thoroughly exercised, and very effective.

materiel (material): Supplies and equipment, It is not known why the Navy persists in spelling it "material."

maximum sustainable indefinitely: The highest tempo of operations that can be continued without increasing loss of capability due to fatigue.

missile batteries: A group or set of missiles; may be a kind of unit.

mission tasking: The particular mission assigned to a multimission-capable unit, or the task assigned to a unit consistent with its mission.

momentum of offensive operations: Maintaining a tempo of operations, rate of advance, *etc.* without offering respite to the enemy.

munitions: Bombs and bullets, *etc.*

National Training Center: Located at Ft. Irwin, CA; a very large instrumented range where near full-scale battles can be fought with realistically simulated weapons and realistic involvement by a great many kinds of units.

onset of hostilities: When the fighting starts.

opposed landing: An amphibious operation against an armed enemy who fires on the Marines as they come ashore.

organic air assets: Armed (close air support) and transport aircraft under the direct control of, or assigned as part of ground units.

personnel performance reserve: How much more task performance can be done before fatigue renders the person ineffective.

personnel reliability: Refers to behavioral reliability of persons who work with nuclear weapons.

physical performance reserve capacity: How much more physical task performance can be done before fatigue renders the person ineffective.

picket: A guard or observer positioned well in front of the main force, usually to give warning of the approach of an enemy. A picket may be an observer outside the defensive perimeter of a ground unit, or a Destroyer far out on the flanks of a battle group.

reconnaissance: Reconnaissance means going to some area and

looking for some class of thing or evidence. (Contrast with search and surveillance,)

recovery period: Time (usually spent sleeping) required to restore performance to some initial state after fatigue.

reinforcement: Adding units to a force in place to increase the force's capability.

reinforcement operations: Preparing to be a reinforcement.

relocation: Movement of a unit from one place to another.

riverine operations: Gunboat operations in navigable rivers or other inland waterways.

rotate watchstanding sections: A watchstanding section is a group of watchstanders who stand their watch at the same time. Rotating the sections means organizing or scheduling watches so a section does not stand watch at the same time of day twice in a row.

search: Search means looking for a particular thing. (Contrast with surveillance and reconnaissance.)

self-deploying: Refers to fixed-wing tactical aircraft, and means that they can be flown under their own power to their ultimate operating area and do not need to be airlifted in larger aircraft or moved by ship.

senior enlisted academy: Formal schools established by each service to train enlisted personnel in leadership and management before promotion to E-7 grade.

sentries: Armed guards protecting some perimeter around a unit against enemy intruders.

servicing: Refueling, lubricating, performing routine adjustments

and cleanup to vehicles (air and ground).

situation assessments: Part of a command-control decision process, where information available about the current situation and environment is analyzed and interpreted prior to choosing a course of action.

small arms: Weapons that can be carried by a man: rifles, pistols, machine guns. Small arms fire means anything coming from weapons which fire 1/2" diameter (".50 caliber") or smaller projectiles.

sonar: Underwater acoustic detection equipment, used to detect submarines. It may either be active (transmits a sound and listens for an echo) or passive (listens for sounds emitted by the submarine).

staff college: An institution of higher learning in military skills, where mid-grade officers develop skills in staff functions such as battle planning, tactical analysis, *etc.*

steady routine: operations and tasks which are continued at some unit level (perhaps company, ship, air wing) which allow some regularity in duty and rest periods and are presumed to be sustainable indefinitely.

strategic forces: Forces which operate intercontinental nuclear weapons (missiles and bombers).

strategy: Considerations in fighting a war or campaign, as contrasted with tactics, which is considerations in fighting a battle or engagement.

strikes: Attacks, usually by aircraft or missiles; against vessels or land targets.

subsystem malfunctions (vehicle): Breakdown of some part or system, usually reducing the capability to perform assigned tasks. Subsystems could be sensors (radars, infrared detectors on tanks), radios, control (steering, *etc.*), and so on.

support logistics operations: Providing the supplies needed to keep a combat operation going. It includes getting the right materiel to the right place at the right time.

support units: Units providing services such as medical, transportation, equipment repair, communications, roads and bridges, *etc.*

surface combatants: Frigates, destroyers, cruisers and battleships. Ships whose mission is to use the weapons installed (guns, missiles, torpedos).

surge: an increased operating tempo when individuals have inadequate opportunity for rest, and which cannot be continued indefinitely because of their fatigue limitations.

surveillance: Maintaining watch over an area. (Contrast with search and reconnaisance.)

sustained duty limiting: Factors which limit endurance on continuous duty.

tactical air(craft): Aircraft whose mission is to attack surface or air targets. Fighter-bombers, *etc.*

tactical forces: An Air Force term, meaning units of tactical aircraft.

tactics: Considerations for fighting a skirmish, engagement, or battle. They address specifics of terrain, details of

systems in place, and so on. Contrast with strategy, which considers longer-term and much more general factors.

technology: The application of science to some problem or need.

technology base: Department of Defense programs in research and exploratory deveolopment, which are not tied to any particular system under pre-acquisition development.

transients: Short-term phenomena.

transit: Movement (usually by ships) from one place to another.

transport forces: Cargo aircraft; troop-carrying helicopters, cargo ships. Contrast with replenishment ships which carry cargoes to be delivered at sea to ships as the receiving ships require.

unit effectiveness: How well a unit can perform its assigned tasks/mission. It is often a function of material condition (the condition of its equipment), manning (how many of its personnel are left), training, and fatigue.

vehicle control: Flying aircraft, driving tanks, fighting vehicles, operating boats, etc.

vigilance tasks: Tasks requiring constant close attention to the task environment (radar scope, ground in front of a picket) often under circumstances not conducive to maintaining the required state of alertness.

weapons systems: All of the parts that go together to perform some offensive task. The F-14 fighter and its AWG-9 radar/computer/Phoenix missile together are a weapons system. The Aegis system (radar, controlling computers, and missiles) are a weapons system. A Hawk missile battery, together with

its radars, fire control computers and data link equipment, are a weapons system. Marines argue that a Marine and his rifle are a weapons system.

CHAPTER 1

SUMMARY AND SCOPE

SUMMARY

General

Acute fatigue, principally simple lack of sleep, is the biological rhythm disruption of greatest concern to military leaders and planners. Air Force planners are also concerned about managing effects of acute upsets from transmeridian travel ("jet lag") in flight crews. (In varying degrees, all Air Force Regulations listed in the references) Chronic disruptions found mostly in Navy operations with watch schedules that begin the rest period six or twelve hours earlier each cycle are not considered a problem. That is, except for Utterback, Ludwig, 1949, no studies on effects or mediations of these customary work-rest schedules were found in the various bibliographies. (Krueger, Barnes, 1989; Krueger, Cardenales-Ortiz, Loveless, 1985; Mackie, Wylie, Evans, 1988) Throughout, the terms "continuous operations," "extended operations," and "steady routine" will be taken to mean operations and tasks that are sustained at some unit level (perhaps company, ship, air wing), that allow some regularity in duty and rest periods, and are presumed to be sustainable

indefinitely. "Sustained operations," and "surge" mean an increased operating tempo when individuals have inadequate opportunity for rest, and that cannot be continued indefinitely because of fatigue limitations. Although in the context of this report, personnel endurance will be considered as the limiting factor to continued operations, often enough materiel (munitions, other supplies), equipment (servicing and repair requirements), or information (command and control decision making, communications limitations, or intelligence and situation assessments) will limit how long high-operating tempo combat or training exercise activity can be continued.

Scope

Department of Defense components (USA, USN/USMC, USAF) are all considered; the U. S. Coast Guard (in the Department of Transportation) is not. Some SOF (Special Operations Forces) problems are discussed, to the limited extent that information about them can be had.

Military Operations Affected by Biological Rhythm Disruption

Military operations which could be affected by biological rhythm disruption in personnel include both combat operations (immediate involvement in fighting) combat support (directly supporting fighting units or groups, such as by providing supply, communications or medical aid). This includes all aspects of land combat

(in place, reinforcement, and expeditionary), support logistics operations, air support operations (tactical and logistic), high-readiness operations of strategic forces, and the operation of naval vessels at sea. The most salient disruption is fatigue, exacerbated by various kinds of stress. Circadian disruption is also encountered, as combat operations events must be responded to as they occur; and events such as strikes and assaults are often planned for what is judged to be the time at which the defender is least effective. The notion of momentum is very important in offensive operations (especially in land combat) and sustaining it for days or weeks entails severe endurance problems. Individuals operate most effectively in a routine work-rest cycle (preferably a 24 hour cycle with rest during hours of darkness including the hours 2:00 AM to 6:00 AM). (Krueger, 1989 and most other references as well) Some element of surprise is always desirable in combat actions (so the enemy cannot anticipate and counter the action). The conduct of extended combat operations (over days and weeks) tends to be more effective if there is no discernible routine to the action: otherwise the enemy could anticipate the next event in a routine. Sustaining effectiveness by dealing successfully with these conflicting goals (regular individual duty-rest routines, but no discernible routine to unit operations) is not

unimportant in tactics and strategy. Full-scale combat exercises (Operational Readiness Exercises, use of the National Training Center, various national and fleet exercises) provide useful exposure to these problems of extended operations, though realistically long exercises (more than two or three weeks) are generally impractical for reasons of fatigue-induced mishaps (injury/death), cost of material, lost/damaged equipment, and limited availability of the training environments.

Military Tasks Requiring 24 Hour Manning

In addition to the military tasks with civil sector equivalents which require 24 hour per day manning (medical, security, communications, ship navigation and propulsion, most transportation system operations, *etc.*) everything immediately involved in combat operations (operating weapons of some kind) must be capable of sustained operations. For the most part, military tasks which have no direct civil sector counterpart will be performed on a 24 hour per day basis. These are aggregated into generic types common across the services for discussion below. Most tasks to perform functions which are also found in the same form in the civil sector are not discussed. The most severe problem in tasks requiring 24 hour/day performance in combat is in command, where at each level a single person has responsibility and the responsibility is sustained; yet judgement, essential to effective command, is most

vulnerable to degradation by fatigue and other upsets in biological rhythms. (Hegge, 1982; Kopstein, Siegel, Conn, 1985; Graber, Rollier, Salter, 1986; Belenky, Krueger, Balkin, *et al.*, 1987; Word, 1987)

Avoiding or Minimizing Performance Disruption

Avoidance or minimization of adverse effects of disruptions is an empirical matter, for the most part. Except for flight operations, where minimum standards for rest duration and intervals are specified for flight crews (and some additional regulations address compensating for transmeridian circadian upset [jet lag]), duty-rest cycle planning is left to local command discretion. Workday and workweek schedules for normal peacetime operations in various circumstances (*e.g.*, in garrison, in the field, deployed overseas, at sea/ashore) are mostly found in manpower requirements planning documents (U. S. Department of the Army, AR 570-2; U. S. Department of the Navy, OPNAVINST 1000.16F) and are not found in use for planning of individual work schedules. As a practical matter, when service members can go home to their families at the end of each work day, their work schedules tend to resemble civilian work schedules. In the field, deployed or at sea, schedules tend toward about 70 hours per week (or whatever seems to be the maximum that can be sustained indefinitely without incurring serious fatigue or motivational problems). In exercises, absolute limiting

factors (that is, until individuals are unable to continue) are often achieved (except in flight crews). Such guidelines as exist for rest requirements are "peacetime use," and not binding in combat. (U. S. Department of the Navy, OPNAVINST 3710.7M; U. S. Department of the Navy, OPNAVINST 1000.16F; U. S. Department of the Air Force, AFR 60-1) This seems peculiar, as conserving resources (or at least minimizing losses of men and equipment due to fatigue-induced degradation in judgement of crews and commanders) is at least as important to successful wartime operations as it is to affordable peacetime operations.[1] (Hegge, 1982; Kopstein, Siegel, Conn, *et al.*, 1985; Graber, Rollier, Salter 1986)

Use of Technical Information and Research Results

Defense-supported research and development in the area of biological rhythm disruptions has concentrated on magnitude of effects. Because of lack of knowledge about combat stress effect interactions, there is some doubt about the precision of predictions which can be made about magnitude of effects under combat conditions. Very little has been done on mediations; most of that has been on pharmacological interventions to facilitate best use of duty and rest periods during transition from one operating routine to another, such as for flight crews going from stateside training routines to European combat-like training exercises where they will fly

overseas and begin operations immediately. Review of the bibliographies and discussions with military officers revealed no cases where practical tools to be used in planning for adequate rest and minimizing biological rhythm disruption in combat were available or under development for "end-users" (senior enlisted and junior officer leaders who do the actual duty and rest cycle directing). As much technical information about biological rhythm upsets, its effects, mediation, and recovery as could be used in such tools actually is available in technical reports, journals, and other publications. Documents to aid the combat leader are too general to support hour-to-hour and day-to-day rest/sleep management planning. (Graber, Rollier, Salter, 1986; Hegge, Tyner, 1982; Kopstein, Siegel, Conn, 1985; Naitoh, Englund, Ryman, 1986; Siegel, Taylor, Shuler, 1983). The "end user" (combat unit leader) is already heavily burdened with devising tactics and methods to stretch scarce resources to meet his needs. He needs planning tools to bring this available but quite general information to bear to assist him in factoring in the sleep needs of his men as a cost and resource with all the other costs and resources. This planning and re-planning often must be done hurriedly as the situation and resource availability changes. None of these R&D results are known to be in a form that could be put to practical use

in improving performance in combat operations.

DISRUPTIONS TO BIOLOGICAL RHYTHMS

Transient Disruptions

Transients are the short-term upsets of the work-rest cycle, usually when transitioning from one kind of operation to another, as discussed below. They are encountered during deployment (*e.g.*, airlift from the United States to overseas locations) or in other changes in operating tempo (such as at the onset of hostilities or at the start of a major operation).

Acute Fatigue

This is what usually comes to mind when fatigue is considered: physiological, behavioral, and performance response to an extended period of duty without opportunity for rest. It is necessarily encountered during transients, and during periods of sustained or surge operations and in training exercises.

Chronic Fatigue

This condition would be found during continuous operations where some rest can be gotten but it is considerably poorer in duration or conditions than would be considered fully restorative. Some striking examples are in ship Commanding Officers at sea, medical internship and for students in the USMC Basic Infantry Officer Course.

Chronic Perturbations to Biological Rhythms

These are disruptions in the normal 24-hour duty-rest

cycle. Daylight rest and duty during hours of darkness are one example, and the eighteen hour duty cycle often found in submarines (six hours on, twelve hours off) or the twelve hour duty cycle found in ships (four hours on, eight hours off) may be even harder to adapt to.[2] (Krueger, 1989; Hegge, Tyner, 1982)

Maladaptations to Biological Rhythm Disruptions

It is observed that some individuals adapt well to shift work, and others do not. Similarly, there is considerable variability in ease with which individuals adapt to the twelve and eighteen hour cycles mentioned above. Measures reduce such idiosyncratic difficulty are not known to be in use; it does not seem to be an issue of concern in research and development planning: at least it has not appeared as a significant concern in Navy research and development planning documents in the last decade.

STRESS INTERACTIONS

Fatigue and other biological rhythm disruptions are not considered as "stress" in this report, primarily for terminological convenience. Stress effects are very difficult to predict, model, or even investigate. The literature and researchers seem to treat both physical/physiological and psychological stresses as dimensionless effects with many causes or sources. Psychological stress encountered (or deliberately introduced) in training and exercises (performance

stress, fear of failure or loss of face, as well as time stress) is the surrogate for combat stress (fear of death or injury). Predictions about performance under combat conditions made on the basis of performance under artificial stresses may be quite inaccurate.[3] "Train the way you will fight" is consummately sensible, but it has some unavoidable limits. Disastrous effects of fatigue on judgment (especially in command) is evident, observed and much discussed in realistic training. (Word, 1987) Training exercise schedules do a good job of adding circadian upsets, as well. Services generally rely on "expert judgment of experienced combat leaders" (mostly introspective/retrospective analyses) to judge whether the training is adequately demanding and how people will perform. However, most investigations of experienced officers' judgments of performance under training stress conditions (mostly fatigue) have shown them to be unreliable. (Neff, Selick, 1983; Word, 1987) It can only be guessed that combat conditions will be at least as bad as training conditions. There is no reason to believe that the added stress of the "fog of war" and of observing attendant carnage/in fear of it will have less effect (less performance decrement) than the elements of peacetime training stress (which may also be present).

Environmental Stressors Increasing the Effects of Biological Rhythm Disruptions

Although these are primarily physical/physiological stresses, discomfort and increased difficulty in getting satisfactory rest or performing task functions may have noticeable psychological effects.

Weather/Climate

Hot and humid weather interferes with effective rest and reduces endurance to physical exertion. It does not seem to have direct effect on more cognitive activity. (Krueger, 1989) Habituation methods (extended calisthenics in high heat and humidity in the days preceding exposure to the environment) have been reported to be effective in US Marine Corps use.[4] The effects of extreme cold weather seems mostly to be protective clothing interference with some task performance. Cold injury (frostbite, chillblains) is an acute physical effect which can usually be avoided. Extreme cold weather does not appear to have adverse effect on performance by disrupting biological rhythms. (Robeson, 1989)

High Latitude Operations

Circadian disorientation caused by extended daylight or darkness may be a problem, as is seasonal (winter) affective disorder (SAD) often observed in members of communities residing in northern latitudes. (Rosenthal, 1989) However, submariners exposed only to artificial

light (much lower illumination levels even than high-latitude winter daylight) for extended periods such as 60-day patrols do not remark on SAD-like effects. A discussion of performance in short-term Marine Corps winter operations in Norway (Robeson, 1989) makes no reference to SAD-like effects, either. In a combat or training exercise setting, SAD phenomena may be too subtle or have too long a latency to be noticeable. If present, SAD would manifest itself as added perception of fatigue or increased difficulty in adapting to changing task environments or task demands. (Rosenthal, 1987)

Naturally Occurring Irritants

Blown sand, biting insects, fungal/bacterial induced dermatitis, etc. are distractions which both interfere with rest and may increase perception of fatigue.[5]

Special Clothing/Equipment

Cold weather protective clothing, chemical agent protective clothing and equipment, body armor, fire fighter protective suits, aviator's exposure suits (to protect against cold water if forced down) all increase exertion required to perform tasks and may induce thermal stress (the same effect as hot and humid weather) as well.

KINDS OF OPERATIONS

Steady Routine

These are regular duty and rest schedules for

individuals. It is the easiest to model, and is characteristic of peacetime operations. Well-managed continuous operations are also a steady routine for individuals.

Relocate-to-Steady Routine

The extra tasks involved in relocation will disrupt individual work and rest schedules, and transmeridian relocations will add "jet lag" to biological rhythm disruptions. Individual effectiveness expected under steady routine conditions will not be achieved immediately unless some additional recovery period (rest) is provided or continuity in routine is enforced during the relocation, a difficult thing to do. Peacetime deployment of non-naval units overseas would have this character; the first day or two at sea for naval units has this character, as well.

Relocate-to-Surge

This is characteristic of reinforcement operations, major training exercises, and the beginning of combat operations. For planning purposes, the beginning of the relocation would be counted as the start of the surge or sustained operations period.

Steady Routine-to-Surge

This is the transition from continuous operations to sustained operations, the onset of hostilities for forces in place, assaults or strikes, and increases in tempo of operations (such as high alert conditions for

strategic forces or "general quarters" for naval forces at sea).

Surge-to-Steady Routine

After some period of very intense operations, return to a more sustainable tempo can be difficult to do gracefully. Without some forethought, this could happen simply by collapse (involuntary sleep) of most of a unit's members. It could be disastrous if the enemy forces were still a threat. The operational concern is therefore to avoid excessive vulnerability or combat ineffectiveness during the transition.

Footnotes:

1. "Peacetime rules" conserve men and equipment. The reasons given for them are usually budgetary (avoid waste). In wartime, one could reasonably expect that the winner will be the one who has the most effective remaining capability (including men and equipment) after some period of combat. An unnecessary fatigue-caused casualty is one the enemy didn't have to work to cause. Peacetime rules for conserving dollars (men and equipment) will usually work for wartime to save the resources for when they are most needed.

2. Individual adaptability seems a little idiosyncratic. In the author's experience, for example, some flight crewmembers adapted readily to eighteen hour cycles at sea (in this case, about ten hours' flight

duties, eight hours for sleep, a shower and a meal), others adapted after some initial difficulty, and a few became ineffective or worse after a few days. The dissociation each day between successive sleep periods is about the same as for eastern U. S. to Germany jet lag (six hours). However, whole segments of ships' organizations (the watchstanders who actually run the engines, boilers, radars, sonars, and who stand the bridge watches) run on twelve or eighteen hour cycles for several months at a time with no apparent ill effect, and no performance decrement (individual or organizational) attributed to the constantly changing relationship between individual work-rest cycles and the day-night cycle. Evidently it is much easier to change sleep periods constantly within a stable 24 hour daylight-dark cycle than it is to adjust to a one-time change in the daylight-dark cycle (as with transmeridian travel).

3. As a simple example, part task trainers (such as fairly simple aircraft cockpit mockups often used in tactical team training simulators for antisubmarine operations) provide only the most limited rehearsal for an actual exercise, in the author's experience. The actual exercise has many more competing demands on crewmember attention (which appear as stresses). Time-stressed response to an emergency condition (a vehicle fire, for example, or some aircraft system

malfunction) is very often much less effective or accurate than it would be in prospect under benign conditions (as when rehearsing for it as part of training). Most persons with combat experience have, or have heard, stories which emphasize near-total loss of cognitive capacity when in great fear. These ubiquitous anecdotal data together with the observations above that training stresses seem to substitute fairly poorly for more realistic stresses, leads to an informal conclusion that actual combat stresses probably cannot be effectively simulated.

4. This acclimation to hot and humid weather by daily calesthenics in slightly higher heat stress conditions was discussed in training conducted for Navy personnel before assignment to Naval Forces Vietnam in 1970. The Marine Corps assessed the effectiveness of the acclimation measures by the much smaller number of heat casualties among newly-arrived units that had undergone the procedure enroute in amphibious force ships.

5. This was discussed in training conducted for Navy personnel before assignment to Naval Forces Vietnam in 1970; it coincides with the author's experience in Vietnam during 1971, the Philippines in 1972, and even in more benign environments (summertime southern Virginia in 1983 and 1988). The irritants both made it seem more difficult to do any task, and interfered with rest, exacerbating the irritation with fatigue.

CHAPTER 2

MILITARY OPERATIONS INVOLVING CIRCADIAN DISRUPTIONS

GENERAL: TRAINING AND READINESS EXERCISES

Exercises to develop combat capability and to measure the effectiveness of the preparation are as realistic as can be afforded. Limits to realism are economics and safety. Exercise duration is usually too short to test wartime-type endurance (cost of munitions, fuel, and equipment maintenance as well as limited availability of training facilities dictates this). Safety and environmental concerns preclude full use of live munitions and fear/stress levels found in actual combat. Exercise duration is also a safety concern, as accident rate (especially involving aircraft) can be expected to go up considerably as fatigue degrades operator and maintenance crew performance.

ARMY OPERATIONS

Deployment

Most military units are "homeported" or "home-based" in the United States; military units outside of the United States are usually there ("deployed") for some limited period until replaced by another of the same kind. This routine deployment is usually be scheduled and

planned well in advance. Individual disruptions in biological rhythms can be avoided or mitigated by planned recovery periods at the destination. "Surge deployment" is in response to some new military requirement (such as the need to show force to support foreign policy in a time and place of tension) and is done on short notice. Deployment usually involves transmeridian movement by aircraft, so jet lag effects would also be present. The requirement to pack up, load, unload, and set up at destination will have the greatest effect on biological rhythm upset, as these are not part of a routine for duty-rest cycle planning: these movement-related tasks are additional transient upsets. As they are not part of what is usually thought of as combat or mission tasks, they are not included in planning. (U. S. Department of the Army, AR 570-2; U. S. Department of the Navy, OPNAVINST 1000.16F).

Reinforcement

Reinforcement means adding more men and equipment to units already deployed, or adding more units to the forces deployed. This would be more urgent and would likely involve requirement to commence operations immediately on arrival at the destination at the same operating tempo as the forces being reinforced. At best, it would have the character of "relocate-to-steady routine" above; more likely it would have the character of "relocate-to-surge." Upsets found in deployment

would also be present.

Special Operations

These are the most difficult to characterize (being irregular almost by definition) and to get information about. However, special operations forces tend to train at continuous operations type tempos with considerable practice at transitions to and from periods of sustained operations, combined with short-notice relocations (often involving transmeridian travel). Both unusual training tempos and relocations give Special Operations Forces considerable experience and practice in coping with biological rhythm disruptions.

AIR FORCE OPERATIONS

Strategic Forces

Strategic Forces are the nuclear deterrent intercontinental bomber and missile forces. Their operations are tightly managed and continuous. Typical duty-rest cycle is 12 hours on, 24 hours off. Realistic exercises involving transition to sustained operations are conducted regularly. (U. S. Department of the Air Force, AFR 28-43, SACR 55-66) The only conditions which are not exercised realistically are the stresses and conditions which would be present during extended nuclear weapons exchange (more than a day or two), for the obvious reasons of personnel and political tolerance.

Tactical and Transport Forces

Tactical forces principally support land warfare (close air support, interdiction of enemy supply lines, surveillance, *etc.*) and consist largely of fighter-bombers. Transport forces provide airlift of man and materiel both from the United States to overseas areas and from overseas supply depots to more remote distribution points. These forces' operations are governed by flight crew sustained duty limiting and rest requirements regulations; support personnel (the ground crews, operations planners, *etc.*) manning is based on shift work assumptions. Thus avoiding or compensating for biological rhythm upset is done reasonably well (U. S. Department of the Air Force, AFR 60-1, AFR 28-40, AFR 28-42, MACR 28-2, MACR 55-1). This appears to be the only case where the importance of planning adequate rest to avoid fatigue-induced performance degradation in wartime operations (to conserve crews and equipment for combat use) is well-addressed (U. S. Department of the Air Force, AFR 60-1, AFR 28-40, AFR 28-42, MACR 28-2, SACR 28-43).

Support Units

These are generally operated on a continuous basis by manning for shift work. Their operating tempo and conditions are similar to Army combat support activities. Support units operate airports, communications facilities, provide logistic support,

aircraft component repair, etc.

NAVY OPERATIONS

Non-shipboard operations have the character of Army or Air Force operations as far as biological rhythm upset is concerned. Shipboard operations have the uniform requirement that some tasks must be performed on a 24 hour per day basis (as they must on merchant ships, as well). Each ship is isolated in its own steel envelope, there are no "outside the base" or "local economy" facilities to provide some relief from the need to perform all of the housekeeping and maintenance tasks, and to be entirely self-sufficient. Normal operations have the character of continuous operations; the sustained operations equivalent is "at general quarters" where battle stations are manned, weapons are manned, and normal duty-rest cycles are not followed.

Routine Deployment

In port, ships maintain duty-rest schedules very much like those of activities ashore, nominally modeled on a 40 hour work week. Transition to the at-sea routine (typically a 70 hour workweek) does not ordinarily lead to biological rhythm disruption. Initially, at least, the 70 hour work week has the same rest schedule, but with longer duty time (Krueger, 1989; U. S. Department of the Navy, OPNAVINST 1000.16F) For extended deployment (western Pacific, Indian Ocean, Mediterranean Sea, etc.) transmeridian travel involves no more than

one time zone change per day, which has negligible disruptive effect.

Short-Notice Deployment

Preparations for short-notice deployment often have the disruptive character of sustained or surge operations, much as preparation for short-notice deployment or relocation would have on Army or Air Force units. Because essentially continuous operations must commence immediately and continue, no in-transit respite is possible.

Independent Operations

When operating as part of a battle group, surface action group, etc., ships divide warfare area tasks (air defense, antisubmarine warfare, etc.) among themselves. Although they operate at a more relaxed level in the task areas they are not assigned, taking responsibility for their part of the group defense means fairly high operating tempo in the tasks assigned. (Such a group of ships would have some specialized to be best at defending against air attack, some at finding and attacking submarines, others at attacking other ships or shore targets. Most such groups are organized around a battleship or aircraft carrier, with major offensive capability.) Coordination between the ships for mutual support and the associated communications places additional workload at the command/combat direction level. In independent operations (a ship operating by

itself), individual ship's mission tasking is either to transit from one assigned location to another or to perform less complex and demanding tasks, such as surveillance. Ships are not generally assigned to independent operations except in a benign environment where all systems can be manned and operated at a more relaxed tempo. For this reason, at sea, independent operations is generally least disruptive to biological rhythms.

Submarines

The essence of submarine operations is in staying undetected, and that, in turn, depends on maintaining a very high state of vigilance against all other vessels in the area which might detect them. Undersea is a significantly more hostile environment than the surface with much reduced time available to respond successfully to mechanical problems which might arise, so propulsion and control (and related systems) vigilance must be high and sustained as well. Ballistic missile submarines operate in a mode which is essentially a combination of independent operations and Air Force strategic forces (intercontinental ballistic missile - ICBM) operations: they have no task but to remain in their assigned location, remain undetected, and be ready to launch missiles if ordered. Attack submarines have a considerably more variable task environment (they may be assigned to a defensive role for some group of surface

ships, or to information gathering - intelligence - or to shadow submarines from another country, etc.). Their operation is on what amounts to a shift work basis, though the shifts normally rotate, six hours on followed by twelve hours off. The twelve hour "off" period is used for rest as well as any other "indirect labor" type functions such as meals, personal administration, etc. The chronic upset of duty-rest period of eighteen hours instead of 24 and the (rare) extended period at general quarters are the only biological rhythm disruption factors. (U. S. Department of the Navy, 1989) Each cycle, the sleep period is six hours sooner, continually rolling back the mismatch with the 24 hour circadian cycle. As discussed in chapter 1, this does not appear to cause significant performance problems.

Surface Combatants

These are all-purpose ships (air defense, antisubmarine, surface target attack, surveillance, shore attack, etc.) to some degree or other, but can't carry the numbers of technicians and systems operators as well as systems and weapons to do all of these, all of the time. Extended periods at high operating tempos (such as operations in an all-threat environment - threat of attack from the air, from other ships and submarines - or at general quarters for extended periods) will lead to acute fatigue in operations personnel (the sensor and weapons systems operators and watch standers), simply because

almost everyone must stay on duty without relief to keep all of the necessary functions performed continuously. Stores replenishment underway (taking on fuel, munitions, foodstuffs, parts) from logistics ships or aircraft carriers while at sea upsets the duty-rest routine of a large portion of the crew required to tend lines, stand extra lookout watches, stow supplies, *etc.* The frequency of underway replenishment depends on the speed the ship must maintain (fuel consumption goes up greatly at higher speeds) and the rate of munitions expenditure (missiles, torpedos, gun projectiles) during the operations assigned. Replenishment every three or four days is not uncommon, principally because combatants try to stay as nearly full of fuel as possible all of the time.

Aircraft Carriers

Aircraft carrier operations are manpower-limited; the limitations are a matter of berthing limits (number of berths, or bunks/lockers that constitute the sleeping and living spaces for enlisted men, and stateroom bunks for officers). There is no space to spare: that not used for sleeping, eating and hygiene is used for repair shops, materiel storage, machinery, operations support (combat direction, briefing rooms, air traffic control, *etc.*) or austere support offices (medical, personnel, records and record keeping). Unlike the practice in earlier classes of submarines where many berths had two

persons assigned, aircraft carriers (and all other non-submersible vessels) maintain a berth for each crew member. Aircraft carriers have personnel for little more than one complete shift of to operate the equipment and do the tasks required to conduct full-scale flight operations. These tasks include moving aircraft around, preparing them for flight, operating catapults and the "arresting gear" (the cables that navy aircraft tail hooks catch to stop them when landing and associated machinery), the fire fighters, control tower and landing signal personnel, air traffic control, and all the operations support of combat mission preparation and control. Full-scale operations means about 120 flights each twelve hours. As aircraft are sent out in groups to perform coordinated missions, the flight operations are more than just a matter of launching and landing aircraft as frequently as possible. "Around the clock" (24 hour per day) flight operations must be much reduced in scope, as the flight deck operations, air traffic control, and combat direction crews must be split into two skeleton crews. This means that (except for some flight crews) flight operations do not involve the kind of rotating work-sleep schedules so common on other ships (~~eight~~ 4 hours on, four 4 hours off, *etc.*). crews ordinarily work about fourteen to sixteen hours each 24; during sustained operations for a short period, they may work nearly continuously (twenty hours

or so each day) for several days. Further, aircraft squadrons embarked are similarly constrained: it is rare for a squadron to get berthing allocation for its full peacetime manpower authorization (which provides for about 1-1/2 shifts of personnel). Even if wartime manning were available to squadrons for support of continuous flight operations, there would not be room for them to go to sea in the carrier. Thus squadrons have nearly the same manpower constraints as the carrier does in its flight operations departments. These constraints are most immediately felt in squadrons whose operations are necessarily sustained (airborne air defense surveillance and antisubmarine defense) and the carrier must rely on its escorts (frigates, destroyers, cruisers, perhaps a direct support submarine) for its defense much of the time. Most of the time, however, these squadrons maintain some level of continuous operations (keeping one aircraft/crew airborne or continuously ready to fly) which amounts to conducting two or three shift operations with 1-1/2 shifts of personnel. This may involve both the disruptions of continuously changing shifts (*e.g.*, an eighteen or twelve hour work-sleep cycle) and chronic fatigue (work period twice as long as the sleep period, instead of the other way around in other ship types). Operating for extended periods at general quarters is even more disruptive aboard an aircraft carrier than surface

combatants because of the far greater amount of movement of men and material from one part of the ship to another in conducting flight operations. (At general quarters, most watertight doors and hatches are kept closed to maintain buoyancy in the event of battle damage. Opening a door usually requires notification of the damage control personnel assigned to maintain watertight integrity, and a wait at each door. Added time needed for most routine tasks requiring movement is considerable. Further, the matter of feeding 5000 or so crew members at their battle stations when access is so restricted is difficult.) Crew members are effectively in a sustained operations mode (no-one returns to sleeping quarters) and incur additional biological rhythm upset. After a period at general quarters, the crew returns to its normal operations mode, which is often near the fatigue limit for most without the added strain of periods at general quarters.

Amphibious Force Ships

These are essentially troop and combat cargo transports with advanced provisions for lighterage (the vehicles which get men and equipment ashore) such as helicopter decks, well decks for launching landing craft and in some, provisions for grounding the bow of the ship for heavy equipment to drive ashore directly in others. Amphibious landings are essentially sustained operations. The transit to the amphibious operations

area (where the Marines will land) is like that of transit of any other group of surface combatants for the ships' crews. For the Marines embarked, crowded conditions may make adequate rest difficult, though a more significant problem may be to conduct activities to sustain physical conditioning and occupy non-resting time productively. Transmeridian circadian upset is not a problem, as transits generally cross no more than one time zone boundary (one hour change) each day. In heavy seas, motion sickness may be a significant stressor, but most amphibious ships are large enough and troop berthing near enough the axis about which the ship rolls, that this is not often a problem.[1] (Aboard a ship for a trip taking a week or more, continuous motion sickness can be debilitating. Even if the nausea and vomiting of motion sickness is not present, heavy seas and more violent ship motion causes fatigue simply by requiring that everyone hang on to something most of the time to keep from being thrown about, or at least feel that he must hang on. Restful sleep is very unlikely when sleepers stay continually braced to resist being thrown out of bed.)

Logistic Support (Supply) Ships

These are the oilers and stores ships which replenish combatants (ships whose mission is to use their armaments) with fuel, foodstuffs, parts, and munitions. Refueling is done "alongside," where high cables

stretched between the two ships support fuel hoses for transfer of fuels. Most bulk stores and munitions are moved as sling loads by helicopters assigned to the supply ships. Supply ships are generally manned adequately to support the tempo of operations they will conduct. Biological rhythm disruptions (or, for the most part, even fatigue) are no more a problem in logistic support ship operations than they are in surface combatants in independent operations.

MARINE CORPS OPERATIONS

Amphibious Assault

The opposed landing (coming ashore against armed opposition) is the essence of Marine Corps operations. It is a very intense period of sustained operations which transitions to continuous operations in a day or two. Although seas and tides are important planning factors in timing of amphibious assaults, most operations seem to be planned to commence before dawn, when a defender is expected to be least vigilant and effective. Fear-induced alertness may very well counter this in the assault force. However, the onset of acute fatigue effects could be expected sooner in the assault force, as well.

Footnotes:

1. The magnitude of ship motion (degrees of pitch and roll and amount of heave) is governed by the

relationship between ship size and wave size. "Deep draft" (including aircraft carriers, amphibious, and supply/refueling ships) rarely roll more than twelve degrees, and pitch about a third of that. Even a twelve degree roll can seem violent sixty or more feet from the roll axis (as on an aircraft carrier flight deck): just below the flight deck (where there is no visual reference to the actual motion), it appears to be a powerful lateral movement. People and objects can be thrown about just as they are on smaller ships with two or three times the angular roll magnitude.

CHAPTER 3

MILITARY TASKS INVOLVING CIRCADIAN DISRUPTIONS

COMBAT AND FORWARD DEPLOYMENT WORK WEEK

Descriptions of the Army combat duty-rest period durations and relationships are found in documents describing manpower planning factors and in studies of problems in continuous and sustained operations. (Rakoff, Marvin, Govedich, 1986; Rakoff, 1987; U. S. Department of the Army, AR 570-2) Availability to combat arms personnel (those in units which do the fighting) of six hours each day for rest is used for planning purposes. (U. S. Department of the Army, AR 570-2) The Air Force makes limitations on flight crew duty periods, minimum crew rest requirements, and special requirements for avoiding adverse effects of jet lag a matter of regulation. (U. S. Department of the Air Force, AFR 60-1, AFR 28-40, MACR 28-2) Non-flying personnel work weeks are less restricted, with up to 72 hours/week work planned (twelve hours per day,six days per week). (Gambrell, 1989) The Navy's flight crew regulations are similar to the Air Force's, though it is explicitly not constraining in wartime. (U. S. Department of the Navy,

OPNAVINST 3710.7M) The Navy non-flight crew plan (at sea) is for an 81 hour workweek (twelve hours per day, nine on Sunday) both peacetime and wartime; it is the current practice while at sea. (U. S. Department of the Navy, OPNAVINST 1000.16F, OPNAVINST 3501.(series))

KINDS OF TASKS

The tasks described here are generic ones, aggregated across the services. Most are not intrinsically 24 hour per day tasks nor are they necessarily associated with shift work. All are ones which can require performance at any time, and whose performance can therefore incur biological rhythm upset.

Physical

These include tasks requiring physical exertion: infantry marches, preparing fortifications, handling supplies, *etc.* Most tasks are performed as external events dictate, by whoever is available or necessarily involved. Performance depends primarily on muscular fatigue (time since start of task); time since last rest (and implicitly, state of rest) and time of day are also factors. Time of day task was started does not seem to provide any significant additional explanation of performance in physical tasks. (Ryman, Naitoh, Englund, 1987) However, there seems to be a large variability in **perceived** effort required to do a physical task according to time of day (circadian cycle). (Johnson, Freeman, Spinweber, *et al.*, 1988) Consequences of

performance decrements are delays, for the most part: the march takes longer, the bunker is finished later, the supplies take longer to stow. Physical task performance capabilities are quite well understood by military leaders, as are ways to plan tasks to get best performance. Physical conditioning is important in all services, principally to maximize continuous performance capability in physical tasks.

Equipment Preparation and Maintenance

This includes assembly, installation, servicing and repair of anything from artillery pieces to communications suites (radio and generator trailers or temporary structures) to aircraft. Preparation will often be non-routine (such as on arrival at destination after relocation) but maintenance is often a routine support function performed on a shift work basis. In some cases, the operators perform servicing and maintenance. In this case, repair time may not be part of the planned workload, and operator performance may suffer from fatigue induced. Performance decrements may lead to errors or inability to determine how to repair. Errors in turn may have serious consequences including loss of life or failure of mission following use of incorrectly assembled/repaired systems or equipment. No special measures are taken to avoid biological rhythm disruption - induced performance decrement.[1] In any case, the six to seven hours' sleep

per day needed to maintain cognitive performance is provided. (Mackie, Wylie, Evans, 1988) Most critical installation or maintenance tasks require some correctness verification (such as quality assurance inspection and maintenance paperwork sign-off) which are intended to detect errors with any cause, including fatigue or circadian upset.

Equipment Operation

This includes operation of weapons and weapons systems, control of power generating systems aboard ship, communications systems operation, use of construction machinery, *etc.* Consequences of performance decrements can be more immediate than for equipment maintenance, and just as severe, especially for weapons systems operation and shipboard systems such as boilers or main engines. The 72 to 81 hour work week plan for Air Force and Navy operations assures sufficient rest to avoid performance degradation, although if additional wartime duties such as general quarters in the Navy or guard duty, *etc.* in the Air Force are required, fatigue may be expected to degrade performance. (U. S. Department of the Navy, OPNAVINST 1000.16F; U. S. Department of the Navy, 1989; Gambrell, 1989)

Vehicle Control

This includes manual control (flying and driving) of land and air vehicles (except for riverine operations (patrol boat and gunboat operations in navigable rivers

such as the Mekong and Bassac in Vietnam), boat[2] operation is episodic and does not figure in extended or sustained operations; performance degradations in boat operation would be quite similar to that in air and land vehicles). In studies of fatigued pilot performance (the pilots were flying simulators) it was observed that physical coordination seemed little degraded even in extreme fatigue. (Krueger, Armstrong, Cisco, 1985) However, judgment was observed to degrade fairly quickly with fatigue onset. (Kopstein, Siegel, Conn, *et al.*, 1985; Graber, Rollier, Salter, 1986; Word, 1987) Performance degradation then would more likely involve failure in mission performance, or incorrectly compensating for external factors such as obstacles, subsystem malfunctions, and requirement to revise plans of action. In the case of aircraft operations, regulations or guidelines are in place to assure adequate crew rest (U. S. Department of the Navy, OPNAVINST 3710.7M; U. S. Department of the Air Force, AFR 60-1, AFR 28-40, AFR 28-42) (though abandonment in wartime could have disastrous consequences). No such guidance is in place for land vehicle operation, and armor (operating tanks) and cavalry (operating lighter armed vehicles) forces are subject to the acute fatigue effects of sustained operations. Fortunately, the consequences of performance decrement in tanks, for example is usually not nearly so dramatic as for

aircraft. There are undoubtedly combat circumstances where severely degraded armor performance now is far more valuable than rested crew performance later; thus prescription of flight crew - like duty-rest cycle regulations may be quite inappropriate.[3]

Vigilance

Vigilance tasks are those that require constant, usually concentrated, attention, often under conditions that do not compel interest or attention. These include sentry and picket duty as well as sensor operator tasks. In some areas (sonar operation, for example), task performance degrades measurably after only an hour or less of duty.[4] (Poulton, 1972; Krueger, 1989) Performance with sleep deficit or in lowest-performance hours (normally between 2:00 and 6:00 AM or so) is also noticeably degraded. (Morgan, Brown, Coats, 1974, 1975) Chronic biological rhythm upset by following a six hour on, twelve hour off watch schedule aboard submarines (or that or four hours on, eight hours off on ships) does not seem to have enough adverse effect to recommend its abandonment in the case of sensor operators, however, although an early experiment developed recommendations for alternate schedules, especially for vigilance tasks in submarines. (Utterback, Ludwig, 1949; Thomson, 1983; U. S. Department of the Navy, "Military Planning," 1989) The consequence of performance decrement is missed detections. In the case of sentries

and pickets, the results will usually be disastrous. In the case of sensor operators, if the signal presentation has some duration, detection may be delayed rather than missed altogether. Vigilance tasks are usually scheduled as shift work to improve likely minimum performance. In Navy operations, when watches are "dogged" the dog watch[5] is usually during the early morning hours when attention tends to be hardest to sustain. (Morgan, Brown, Coats, 1974, 1975)

Command

This includes commanders and their agents such as combat direction officers, officers of the deck, mission commanders, *etc.*: anyone with the authority to take tactical action on behalf of a combat unit. It also includes lower level functions such as air traffic control and other directive activity. As it involves judgment and planning, it is most vulnerable to performance degradation with fatigue and biological rhythm upset: judgment is usually the first facility to be degraded by biological rhythm upset, and it is very difficult for an individual to monitor in himself. (Hegge, 1982; Kopstein, Siegel, Conn, *et al.*, 1985; Belenky, Krueger, Balkin, *et al.*, 1987) Usually, the more his judgment is degraded, the less likelihood is that the commander will become aware of it or believe evidence of it. (Word, 1987) There is a sometimes unfortunate "I can hack it" tendency in those who are

otherwise temperamentally well-suited to be effective commanders which makes them vulnerable to fatigue-induced loss of effective judgment. It appears that an important side benefit of extended National Training Center exercises is to demonstrate this phenomenon to commanders and other leaders, with the desired effect of convincing them that, although their responsibility is 24 hours per day, they will not be able to discharge it successfully unless they take care to enforce some sleep discipline for themselves. Adverse consequences of degraded command performance include ineffective or inappropriate decisions which may lead to failed missions or at least inappropriate use of resources, and loss of effectiveness of the unit commanded.

Tasks With Civil Sector Equivalents

Hospital and medical, police and security, administrative and other clerical, and transportation operations such as ship navigation and propulsion, air transport, and truck transport are not appreciably different in military and civil sector environments, and are not specifically discussed.

REGULATIONS AND GUIDANCE ON MEDIATING CIRCADIAN DISRUPTIONS

Planning Factors

Planning factors are used in determining manpower authorizations, by specifying the methods and

assumptions used to determine how many people and with what combinations of skills and qualifications will be required to perform assigned missions. They contain the assumptions about duty periods and rest which will be available in combat environments. (U. S. Department of the Army, AR 570-2; U. S. Department of the Navy, OPNAVINST 3501.(series)) Manpower is always a scarce resource: each mission and function must compete for its share of authorized end strength (the numbers in each pay grade that Congress authorizes for each service as of the end of the year). Manpower planning (using the different planning factor methodology in use by each service) is highly visible in each service, as it adequate manning is critical to the effectiveness of every command. For reasons of high visibility alone ("everyone's a critic") planning must be done carefully. To the extent any errors are made in the development of planning factors, they seem usually to be on the side of overestimating individual endurance or performance under stress. (Neff, Solick, 1983; Word, 1987) They also tend to assume a steady routine, and do not account for the adverse effects of the frequently added transient demands of relocations, changes in operating tempos, recovery from degraded performance during sustained operations, and so on. To plan for these transients between different kinds of steady-state operations, planners would have to specify the details

of each kind of transient or transition: to prescribe how long each would take, and the conditions for each. This is probably not feasible: number of kinds and variability in conditions determining their nature would be so large that any result, even if affordable, would not be useful. As the transients are relatively brief in comparison with the duration of steady-state conditions before and after, they are usually ignored. Most planning also fails to provide for graceful degradation, *i.e.*, useful residual performance after significant personnel and equipment casualties (which would also provide for useful residual performance after significant performance degradation even without casualties, but as a result of acute fatigue and other biological rhythm disruption). To be useful, however, planning which considered this would have to make assumptions about numbers and mixes of casualties. A realistically comprehensive plan could be expected to be intractably voluminous, because of the large numbers of combinations that should be considered. Manpower planning actually seems quite well done, considering the impracticality of extending it to comprehensive inclusion of transients (transitions) and effects of casualties.

Guidance

For the most part, effective guidance is explicitly waived in wartime operations. Guidance on rest and sleep

requirements address training conditions. (U. S. Department of the Navy, OPNAVINST 3710.7M; U. S. Department of the Air Force, AFR 60-1). This may be inappropriate, as fatigue-induced performance decrements, and men and equipment losses due to fatigue-induced mishaps may amount to doing to ourselves in wartime what an enemy would otherwise have to expend resources to do.

Flight Crews

This is the only area where very explicit guidance is given. Most Air Force Mobility Regulations (AFR 28-40, 28-42, 28-43) do give guidance that could be construed to apply to wartime operations. The consequences of biological rhythm upset induced mishaps with loss of life and equipment could be more serious in wartime than in peacetime, when loss of irreplaceable resources could be a critical disadvantage.

Command

There are currently no regulations or guidance in this area. The military experience base (Army commanders, principally from National Training Center exercises; Navy commanders with ship command experience) seems adequate to support appropriate practice (rest discipline self-imposed by commanders).[6]

Guidance for Wartime Operations

This is generally inadequate.[7] Information available to support informed decision making or guidance development

is not in realistically useful form. Methods of decision theory (decision making under risk) are applicable in principle, but developing the tools which could be used under combat conditions to make appropriate contingent and tradeoff decisions would be difficult indeed, if even possible.[8]

Footnotes:

1. Literature, bibliographies, and known research programs do not address this.

2. A **ship** carries **boats**. Submarines are usually referred to as boats for this reason, even though many of them are larger than smaller Navy ships such as frigates. Boats are most often used for carrying people between ships at anchor, and to shore, though riverine forces are comprised of boats and "yard craft" (tugboats and the like that do harbor and shipyard work) are also included.

3. In air operations, the consequence of severely fatigued performance degradation may very well be loss of aircraft and crew. In ground vehicle operations, the consequence will rarely be so severe. The worst case (in the case of armed vehicles such as tanks) could be errors in weapons use, sometimes causing damage to one's own forces. However, it should not be difficult to imagine battle circumstances where all available forces are needed at some time even if they will not be very

effective and their effectiveness in the near future may be efen more degraded. This "maximize net present value" sort of idea explains why the effects of fatigue and other biological rhythm upsets may be accepted rather than mediated in some wartime circumstances.

4. The SH-3 helicopter has a sonar which is lowered into the water when the helicopter is in a hover, to search for submarines. The original "A" model (1961-1971) carried two sonar operators who alternated operating the console which slid from in front of one to the other. Standard procedure was for each operator to work the sonar for half an hour before being relieved by the other. The rationale was that performance in this vigilance task was known to degrade significantly in 30 minutes. This rationale was sufficient tocause acceptance of a design that provided a relief crewman even in a time of scarcity of manpower and funds.

5. A dog watch is one or two watch periods in the day that is shortened to rotate the watch period commencement times, or create a different number of watch **periods** than watchstanding **sections** to rotate watchstanding sections through the watch periods). This may make it possible to either avoid or permit an individual to stand his watch at the same times every day without either changing the number of "shifts" (watchstander sections or groups of watchstanders) or the length of each "shift" or watch.

6. Senior commanders are generally selected from those more junior commanders who have successfully coped with various (mostly chronic) biological rhythm upsets (unsuccessful coping will generally result in unacceptable performance and no promotion in rank). To the extent there is ever any benefit from "micromanagement" in the armed services, it is where it does provide quick feedback to a commander of inadequate performance or judgment, including lapses due to fatigue or other biological rhythm disruption.

7. As discussed in earlier sections, most guidelines only address limitations to peacetime operating tempos, usually to reduce aircraft accidents. Wartime planning factors generally do not give guidance: they attempt to predict what a commander will actually use.

8. Ideally such a tool would help a commander make cost-benefit tradeoffs that considered all relevant factors including sleep and consequences of performance degradation with unmediated biological rhythm disruption, and aided him in planning efficient mediation. As a practical matter, such calculi are ordinarily quite difficult even in a benign classroom-type situation with little time pressure, relatively little uncertainty about the immediate future, and relatively few factors to consider. (This kind of complex planning and decision making is often professionally aided, in formal "decision conferences.")

Useful tools would probably have to be enhancements of tools already at hand and in use to reduce complexity in management of combat resources. For the Army/Marine small unit commander, the tools may just be some procedural mnemonics which can not be extended to deal with additional complexity. In most other cases where there is come kind of computer support for resource management (fuel, weapons, munitions, *etc.*) the facilities might be capable of enhancement to include manpower performance reserves. Planning support methods are another matter, however; poorly designed aids may be worse than no aids at all.

CHAPTER 4

CIRCADIAN DISRUPTION-INDUCED PERFORMANCE DECREMENTS AND INTERVENTION STRATEGIES

EXPERIENCE WITH PERFORMANCE DECREMENTS

Each service has significant experience in realistic exercises that expose some vulnerabilities to performance decrement from biological rhythm upset.

Army

Large scale training exercises conducted at the National Training Center seem to provide the richest experience in coping with biological rhythm upsets ensuing from transmeridian deployment and continuous and sustained combat operations. If resources permitted (limitations are mostly constrained training budgets and limited availability of and competition for large scale training facilities), long-duration exercises would support development of even better understanding of the conduct of continuous operations. These are not research exercises, or vehicles for doctrinal development. They are conducted to train leaders (enlisted and officers) to achieve the necessary state of readiness (including practical experience in coping with and minimizing effects of biological rhythm disruption), and must be

repeated regularly to sustain unit proficiency.

Air Force

Strategic Forces

Strategic forces operate on a routine carefully designed and controlled to sustain operations without performance decrement. Personnel reliability (maintaining assurance that personnel with access to nuclear weapons do not do anything inappropriate (act without authority or fail to act when directed), and sustaining the capability for sound judgment are the primary concern; strict avoidance of performance decrement is the standard.[1]

Tactical Forces

Tactical forces (as well as support forces and groups) participate in exercises which provide some degree of combat realism. Air Force regulations controlling duty-rest cycles for flight crews are reasonably effective in precluding performance decrement. Adherence to the 72 hour deployed workweek standard for non-flying personnel even during training exercises will also generally prevent performance degradation caused by biological rhythm upset. (Gambrell, 1989)

Navy

Major fleet exercises (Operational Readiness Evaluations, National Exercises, *etc.*) provide limited experience in biological rhythm disruption - induced performance decrement. Most ships are manned to

support continuous combat operations as a matter of at-sea routine. A limiting factor in fleet operations is the ability of aircraft carriers (and the embarked air wing) to conduct continuous flight operations. Commanders and planners are well aware that the consequences of fatigue-induced performance decrement in flight crews include aircraft accidents, often with loss of life. Their prudent unwillingness to gain practical experience in these performance decrements, limits effectively sustained operations to two or three day periods, which is how long it usually takes to "use up" (induce acute fatigue in) available flight crews. During operations when a two-carrier battle force can be formed, high-tempo 24 hour per day flight operations are conducted, each carrier conducting essentially normal operations for twelve hours of the 24.

Marine Corps

Marine Corps combined arms exercises (Twentynine Palms, CA) provide excellent experience in continuous and sustained operations. Exercises may last several weeks, and learning to sustain combat capability is an important part of the training objective. Amphibious training areas (bases in California and North Carolina with assault beaches for landing practice from amphibious ships) are used to good effect to practice full-scale and full duration opposed landing exercises. Organic air assets (squadrons trained and assigned to

provide thoroughly integrated air support) capable of flying from amphibious ships are subject to the same flight crew duty-rest cycle regulations as Navy flight crews: they are governed by the same general regulations. (U. S. Department of the Navy, OPNAVINST 3710.7M) Because amphibious assault tends to be a fairly short-duration operation, some tendency to exceed these limits for the first 36 to 48 hours of an assault operation could be expected. Marine Corps fixed-wing tactical aircraft are essentially self-deploying (they can fly from their stateside bases to their operating area) much as the Air Force is. The difference is that Marine Corps Air Groups and Wings can be expected to deploy to expeditionary airfields (often featuring metal matting laid over compacted earth, built in a day or two) and to be assigned to be controlled operationally by the ground forees they support. This in turn means that they will be exposed to the same operating tempo as the ground forces. Thus they may find it difficult to perform all of the missions assigned without experiencing biological rhythm disruption - induced performance decrement, and may find it very difficult to stay within flight crew duty-rest cycle guidelines.[2]

PERFORMANCE DECREMENTS, CONSEQUENCES, AND MEDIATION/INTERVENTION

Physical Tasks

Operations which are principally physical are infantry movement and the unloading and distribution parts of resupply evolutions. Work slowdown would be the performance decrement most often seen. Physical conditioning is important to military operations primarily because fit personnel have more endurance in the performance of physical tasks. Planners and commanders usually have a good understanding of the physical endurance of their men in their units and a reasonably accurate appreciation of the fatigue level at any time. They tend to make realistic plans accordingly, because they know how. Little other mediation or intervention is possible, except not to try to use what is not there in remaining capability. The ability to sustain physical activity levels is little affected by moderate sleep loss or other circadian upset (Haslam, 1982; Belenky, Krueger, Balkin, *et al.*, 1987; Vogel, Sampson, Wright, *et al.*, 1979), although subjective perception of fatigue is very sensitive to the circadian cycle (with greatest fatigue perceived between 2:00 and 6:00 AM). (Johnson, Freeman, Spinweber, *et al.*, 1988) If there are major interruptions to sleep routines during relocation before a period of intense operations, the duration or

intensity of the surge (sustained) operations which can be performed effectively will be reduced somewhat. (Hegge, Tyner, 1982; Belenky, Krueger, Balkin, et al., 1987) Physical rest is required (no physical activity) to recover from acute fatigue from extended surge operations. The risk is that when the sustained operations limit is reached, units will transition to no operations at all (everyone will collapse or at least be incapable of maintaining a useful defensive capability) and will be excessively vulnerable.

Equipment Preparation and Maintenance

Most of this kind of operation is in rear support areas (or aboard ship) where shift work routines could be maintained. Performance decrement would show itself as production errors; units supported would suffer the consequences of reduced ability to get safely operable equipment or vehicles. Fatigue-induced errors could have the effect of creating equipment losses or systems casualties. Chronic fatigue or other biological rhythm disruption is relatively unlikely, as work environment, tool and equipment availability, and repair parts supply would tend to limit the tempo of this kind of operation. Although moderate physical exercise (normally part of this kind of function) is detrimental tosustaioned performance (Naitoh, Englund, Ryman, 1987), the work performance is rarely sustained beyond the half day or so of a normal shift. After a relocation, time required

to set up equipment could delay time when normal operations could commence, and the first shift would likely be somewhat ineffectual due to fatigue or other biological rhythm upset. The normal level of effectiveness should be restored within one shift, as the next shift could be expected to have a normal rest period before work. The intensity of work is generally limited by available tools and facilities, so the acute fatigue and disruptions, as experienced by combat arms personnel during sustained operations, would generally not be a factor. Limitation on quantity of work which can be done are largely the availability of tools, work space and repair parts; at most, duty periods could be expected to increase by 50% to a 100-120 hour workweek.[3] Performance decrement could begin to be a problem within a few days of insufficient sleep under these extreme conditions. (Krueger, 1989)

Equipment Operation

Artillery, combat engineers, communications, and shipboard engineering functions are typical operations. Operational consequences of performance degradation can be severe (artillery fire on friendly forces by mistake, ineffective defense against air attack, garbled or incorrect operations orders, explosions or fires in shipboard engineering spaces or catastrophic system casualties, *etc.*). For field weapons operation such as artillery, practical mediation/intervention is limited

to indoctrinating enlisted and officer leaders with the importance of rest discipline to assure continued adequate performance. In more industrial settings (communications, shipboard operations), performance degradation conditions are less likely as shift work conditions tend to prevail, and surge levels of operation are not much different from steady routine operations. A relocation (or at least the activities on arrival at destination) could amount to surge operations for artillery and combat engineers; for others with schedules much more like shift work, full operational efficiency should be expected within one shift (when rested personnel relieve the first, unrested, shift). (Relocation, in the sense considered here, does not apply to shipboard personnel.) During training, adverse consequences of performance decrements to weapons systems operations (artillery, missile batteries, etc.) are rarely allowed to develop to a realistic levelduring a long period of sustained operations. This kind of experience (realistic performance degradation after lengthy sustained operations) could be very costly in lives and equipment.

Vehicle Control

This is the operation of aircraft, mobile weapons systems (tanks, etc.), boats (riverine forces as well as ship's boats and amphibious landing craft) and road vehicles. Performance decrements can be most

spectacular (especially in the case of aircraft crashes) and often involve loss of life and equipment. Armed vehicles (aircraft, armor, riverine forces) may have just as significant performance decrements which are not so spectacular: mission failure (target not bombed; hostile submarine periscope not seen; landing zone not found; uncoordinated fire-and-maneuver leaves a squad unprotected; *etc.*). The initial performance decrement is to judgment, critical to mission performance in armed vehicles: thus any performance decrement due to biological rhythm disruption can have serious consequences. Flight crews are protected against simple fatigue disruptions by regulations limiting duty periods and prescribing minimum rest periods (though some regulations are waived for actual combat conditions when they may be needed most). Circadian disruption is mediated in some cases by pharmaceuticals (L-tryptophan to facilitate scheduled sleep without "sedative hangover" (Spinweber, 1987; DeJohn, 1989), some low dosage stimulants to improve landing performance after very long flights,[4] and regulations in other cases (prescribing extra recovery periods following transmeridian relocation). (U. S. Department of the Air Force, AFR 28-40, AFR 28-42, MACR 55-1) Finally, a consequence of insupportably high operating tempo may be to "use up" available flight crews creating a lapse in operations (with no-one adequately rested to fly safely

or effectively). No such crew rest guidelines are provided in the case of land or water vehicle operators and crews. The nature of most non-air vehicle operations (including tactical or armed vehicles) does not make them quite as vulnerable to loss of effectiveness when crew judgment performance is compromised, at least in part because mission environments are less complex. Minimizing performance decrements in non-air vehicle operation is, however, a matter of foresightedness and judgment acuity of local commanders and leaders, and not a matter of formal regulation.[5] Judgment performance decrement is somewhat sensitive to conditions at the start of a sustained operations period. Starting with biological rhythm disruption will likely accelerate performance degradation. (Krueger, 1989) Graceful relaxation from sustained operations to continuous operations may be a particular problem when limiting sustained operations endurance was reached: to re-establish continuous operations, some crews must continue operations during the first duty period. Ground units may risk dangerous vulnerability to hostile action during the initial recovery period from acute fatigue of sustained operations.

Vigilance

Vigilance operations involve close and continuous attention to the task environment, often under

conditions not conducive to alertness. They are most critically characteristic of defensive operations (sentries, pickets, air defense radar and electronic surveillance, sonar, *etc.*). Performance degradation manifests itself as missed detections of one kind or another. Operational consequence of a performance decrement depends entirely on the extent of the missed detection: if the event which was supposed to be detected is missed entirely, the consequence is failure (a terrorist gets past sentry and successfully places a demolition device; inadequate warning or preparation is afforded against a counterattack; no resistance is offered to an air strike; a submarine gets within weapons launch range of a battle group). If the detection is late, the consequence may be less serious (some, but not all defensive measures can be taken, for example). Vigilance tasks are typically performed only during part of a duty period; acceptably acute vigilance cannot be sustained in many task areas for more than a few hours at a time at most. Relief from the vigilance task is the most reliable mediation known. (See footnote 4 to chapter 3.) Some evidence indicates that introduction of artificial stimuli (in the absence of real signals) may help maintain sensor operator (sonar) vigilance, (Poulton, 1972) though other evidence indicates introduction of artificial signals may be an overall detriment to vigilant performance in more

realistic environments. (Krueger, 1989) Some biological rhythm upsets have noticeable adverse effect, even when adequate rest is afforded (Krueger, 1989; Mackie, Wylie, Evans, 1988), though the chronic disruption of twelve and eighteen hour work-sleep cycles aboard ships and submarines does not seem to have enough adverse effect to concern commanders and crews of them. The rapid degradation of vigilance performance with fatigue is widely understood by planners and commanders, and it is rare to see tactical plans which place unwarranted reliance on long-duration vigilance performance. Performance is generally lowest in the pre-dawn hours regardless of state of rest. (Naitoh, Englund, Ryman, 1986) During requirements to maintain vigilance in sustained operations, naps can be effective, especially if taken during the pre-dawn 2:00 AM to 6:00 AM period. Methods (other than regular sleep) of stimulating sustained vigilance are not known. (Kreuger, 1989) If suffering extreme fatigue, the "sleep inertia" following a nap is particularly severe and long-lasting after naps during this period. (Naitoh, Englund, Ryman, 1987; Naitoh, Angus, 1987) Substantial recovery from acute fatigue or other biological rhythm disruption can be achieved in about a day; full recovery from fatigue-to-collapse may take several days. (Kopstein, Siegel, Conn, *et al.*, 1985) If all vigilance duty personnel are "used up" during a

period of surge operations, no measures can be taken to stimulate a few to acceptable performance levels for vigilance duty while the remainder recover by sleeping.

Command

This includes leadership functions at all levels. Leaders generally feel they should stay awake and involved during continuous and sustained combat operations to see to their responsibilities. However, effective leadership depends on unimpaired judgment; fatigue and other biological rhythm disruptions impair judgment. Avoiding or minimizing biological rhythm disruptions is therefore critical to successful combat leadership. In the Army, in particular, there is growing awareness of the importance of sleep discipline as a combat skill and its importance to effective leadership. (Word, 1987) Development of tools (easily worked rest planning methods for various operations and circumstances) which are practical for use in the frantic confusion of combat would support this requirement. Concern for organizing adequate rest for his men is one of the things a leader loses sleep over. The tradition, "First see to your men, then yourself," tends to make it more difficult for leaders to get adequate rest during changes in operations or operating tempos. Transition to surge or sustained operations is exacerbated by the traditional leadership practice of asking subordinates to do no more than the leader does,

including forgoing sleep. A leader will soon become ineffective unless he takes care to get adequate rest even when his men can not. Only when it becomes doctrine for the responsibility of a leader to include the duty to maintain himself in an adequately rested state, can this problem be solved. When relaxing from sustained operations to continuous operations, the unprepared leader will likely not have sufficiently good judgment to prepare his unit adequately against the increased vulnerability that usually attends reduction in operating tempo, especially at the end of their effective endurance. The effective leader will have planned for some reserve as well as delegated appropriate authority for times he is resting, so that any transition to a reduction in operating tempo will have minimum risk. (Word, 1987)

Footnotes:

1. Each service has a tightly controlled Personnel Reliability Program which covers all persons who have duties involving access to nuclear weapons (from the technicians who put them together and do maintenance on them, to the crews who prepare them to fire or be dropped, and the crews who drop or fire them). The program involves background checks, regular reviews by medical officers and commanders, and annual certification of behavioral reliability for each person in the program. The program is taken very seriously,

and appears to meet its goals (at least from 1963 to 1980, there were no procedural changes or additions to the program which would have indicated that some additional measures needed to be taken).

2. To be responsive to the supported unit's needs, the air support elements must try to provide whatever is asked, as promptly as possible. During the heat of battle, especially if it is extended over several days or weeks, supported units could need more missions flown than can be done within flight crew fatigue limitations. The air unit planner is in a delicate situation: whether to risk aircraft and crew loss in a fatigue-induced accident (and reducing assets available in the future) by meeting some immediate need, or to deny a request to reduce risk and conserve resources. In the case of Air Force close air support, the air units (and approving authorities) are remote, and it is easy to deny requests (as well as develop a lasting reputation for being unresponsive). The intimate working relations between Marine Corps air and ground units is extremely effective, but it has some drawbacks.

3. Most equipment maintenance shops seen could probably support up to half again as many workers as are normally assigned, without serious loss of efficiency (physical interference or all tools in use). This is a rough estimate and unsupported generalization.

4. The references (notably DeJohn, 1989) speak only of

use of methamphetamine and other stimulants in low dosages as research issues in improving landing performance, especially on aircraft carriers, after extremely long flights. However, in discussions with Navy pilots between 1970 and 1980a number of them describe use of amphetamines provided by flight surgeons for this purpose, particularly in long-range attack aircraft operations with final landings aboard a carrier.

5. That this is the case, and not even a matter of current training or common doctrine, is reinforced by discussions with Army reservists immediately after extended drill (active duty) periods.

CHAPTER 5

RESEARCH AND TECHNOLOGY PROSPECTS

RESEARCH

General Character

Basic and Applied Research

Defense basic and applied research (category 6.1 funding) is mostly unclassified work; the majority of it is conducted in university laboratories under grants and contracts planned and managed by the Army Research Office (ARO) and Army Research Institute (ARI) Office of Basic Research; Office of Naval Research (ONR); and Air Force Office of Scientific Research (AFOSR). Aggregate funding is somewhat less than $1 billion. (Defense News, February 5, 1990) Over the last five years or more the director of ONR, at least (controlling over a third of all Department of Defense research funding) has curtailed or limited work not of a physical science or engineering character. Programs in the behavioral and management sciences (engineering psychology, training psychology, group psychology, organizational theory, economics, operations research, decision theory, *etc.*,) have been eliminated.[1] Recent congressional direction (early spring of 1989) to organize research and

development programs to support the requirement to consider manpower, personnel and training factors in systems acquisition (Department of Defense Directive 5000.53 of 31 December 1988) has not been followed, at least in ONR.[2] No Navy or Air Force research is known to be underway to increase understanding of biological rhythm disruptions and stress interactions under combat conditions, to characterize methods for measuring their effect, the efficacy of measures to avoid or reduce performance decrements, or design methods for tools or aids for field use.[3] However, Army basic research in this area has been stable, perhaps in part because behavioral and physical sciences are pursued in separate organizations, ARI and ARO, respectively. In a recent Broad Agency Announcement in the Commerce Business Daily, ARI described research programs in the areas that seem most important to support the solution of these problems in biological rhythm disruption.[4]

Exploratory Development

Category 6.2 funding (in the aggregate, over $2.4 billion) supports work in the technology or applications end of the technology base (which is 6.1 and 6.2 funded work together). Most of it is used to support work in the services' research and development centers, though some goes to industry or universities. Directors and managers of exploratory development programs have been considerably more responsive to service needs for work

in the behavioral and management sciences, and to the congressional direction of early 1989.[5] However, the fundamental (6.1) work to support extended 6.2 progress is not evident in plans or prospect, except by the Army. No work is known to be in progress or prospect in development of practical tools or methods for putting already developed knowledge about performance effects of biological rhythm disruptions and mediations into practice in the field to improve operational capability.[6]

Completed

Most research and development in this area has focused on characterizing and measuring simple task performance under fatigue and other biological rhythm upsets; decrement and recovery time quantification have been the principal results. Some very good summaries of the more applied work have been written, suitable for use in staff college or senior enlisted academy training. (Belenky, Krueger, Balkin, *et al.*, 1987; Naitoh, Englund, Ryman, 1986; Siegel, Kopstein, Federman, *et al.*, 1981) They summarize what is known about endurance and performance decrements in military environments and rest requirements to restore performance levels. Some work on safe pharmacological interventions for flight crew use has been completed and some results are in use. (Gambrell, 1989; DeJohn, 1989)

Current

Most current work focuses more on physiological processes than behavioral ones.[7] Decrements in performance involving judgment (those that can have the widest and most serious consequence in a combat environment because they affect the directing of force) are also the most difficult to model and measure so that results will be reliably applicable in the complicated combat environment. Work is not known to be in progress for useful characterization of combat stressors, which would be needed to support understanding of how to predict performance decrements in actual combat conditions.[8]

TECHNOLOGY: USE OF RESEARCH RESULTS

Far more is known about mediation and compensation for performance decrements induced by biological rhythm disruption than is implemented.[9] In benign and stable environments, systems similar to personal computer - based project management applications software could, in principle, be used. However, in any environment permitting their use, performance decrements which could be reduced or avoided would probably be far less costly than the effort to use the systems to reduce or avoid them: the cure might be worse than the problem.

PRACTICAL NEEDS AND POTENTIAL GAINS

Combat leaders and planners need tools to make best use of personnel performance reserve (how much longer they

can sustain some level of performance) with the same facility they can deal with water ration sufficiency, maneuver capability, weapons and munitions availability, fuel reserves, *etc.* Performance capability is somewhat more difficult to deal with because it is not static: it decreases inexorably in use, and takes time (when personnel are not functional) to restore. A practical need is for ways to model performance capability very simply so that leaders with essentially no spare attention resource can consider it usefully, individuals can understand and attend to their own essential needs effectively, and communicate their status accurately. Once, maintaining water discipline meant staying in a mild state of dehydration; with good understanding at the leader and individual level that full hydration is necessary to full performance, water discipline now means insuring full hydration. The potential gain for field-usable tools and models is to enable efficient use and reliable planning of performance resource in continuous and sustained combat. Combat leaders are practiced in making most effective use of limited resources of firepower, mobility, information, and supplies as a matter of professional competence. Tools and models to enable them to plan and manage the use of an equally important limited resource, personnel performance, could add another dimension to efficient and effective use of combat resources. Well-designed

tools and methods could incorporate new information about performance decrements under actual combat stress, as it becomes available.

TECHNOLOGY IMPLEMENTATION METHODS

Two possibilities naturally come to the American mind: build an electronic (computer) device to do the job, or train everyone in the technical principles (the psychology and physiology of biological rhythm disruptions) to inform their planning and actions. The former is impractical (at least for small Army and Marine units) because it requires carrying and interacting with some device in a hostile environment by persons with no time or attention resource to spare. The latter has been attempted to a degree by publication of briefing information summarizing performance capabilities in continuous and sustained combat. What is lacking is the kind of characterization which would permit performance capability to be considered and data maintained in the way and at the same time other combat resources are assessed and their expenditure planned. Once developed, use of these methods and models could be taught as a combat skill just as weapon employment, attack and defense planning, maneuver tactics, and other staff and tactical planning is now taught at all levels.

Footnotes:

1. Most of these programs were eliminated during

reorganizations in 1981-1983 during the author's tenure at ONR. More recent reorganizations in the Life Sciences Directorate (1985-1987), mostly during the author's tenure at ONT, eliminated programs in group psychology and organizational behavior and reoriented all programs to emphasize neurobiological aspects.

2. This was discussed in some detail in a Naval Health Research Center, San Diego sponsored workshop on April 4 and 5 on "The Combined Effects of Multiple Stressors on Operational Performance." The letter was discussed at length, but copies were not be made available. The responsiveness of Department of Defense Directive 5000.53 to the letter was also discussed. The Director of ONR subsequently asked for a responsive research program to be developed, but he declined to fund or approve any of it in 1989.

3. Review of Navy R & D programs from 1986 to 1989 showed nothing focused along those lines; available references show no completed Air Force work in these areas, either.

4. The announcement (in September or October of 1989), soliciting research proposals to investigate biological rhythm upsets in realistic conditions and to examine mediations, is not maintained on file locally.

5. For example, the Director of the Office of Naval Technology asked his Human Factors and Manpower, Personnel and Training technology area manager for

proposals in support of the directive, and subsequently made some funds available to support them.

6. Work that is oriented toward the use of R&D results in decision aids and planning tools has not been found in bibliographies or reviews of the various programs. As discussed in chapter 4, developing useful tools would be an ambitious undertaking.

7. Programs discussed in the workshop (note 2) and seen in reviews of Navy programs and Army solicitations seem to emphasize development of quantitative physiological measures that could be used to predict performance and endurance. Empirical field-usable measures and mediations are not emphasized. The latter is not science (research) or technology (immediate application of science) and is not particularly attractive to program managers who must justify their programs on the basis of scientific and technical merit. Applications are really only technology challenges in the field of decision aiding and man-machine interface concerns in applied psychology.

8. This is easy to understand, because it may not be possible to replicate or develop realistic surrogates for combat stressors which are both technically sound and acceptable for use with human subjects.

9. The difficulties in doing this are mentioned in note 8 to chapter 3, in chapter 4 and in note 6.

REFERENCES

Belenky, G. L., Krueger, G. P., Balkin, T. J., *et al.*, Effects of Continuous Operations (CONOPS) on Soldier and Unit Performance: Review of the Literature and Strategies for Sustaining the Soldier in CONOPS, Walter Reed Army Institute of Research, U. S. Army Medical Research and Development Command, U. S. Department of the Army, WRAIR Technical Report No. BB-87-1 (Washington, DC, April 1987).

DeJohn, C. A., Effects of Psychophysiological Countermeasures on Performance Decrement During Sustained Flight Operations, Naval Aerospace Medical Laboratory, Naval Medical Research and Development Command, U.S. Department of the Navy, Research and Technology Work Unit Summary FY89 Addendum, Accession Number DN 248502, 1989.

Englund, C. E., Ryman, D. H., Naitoh, P., *et al.*, "Cognitive Performance During Successive Sustained Physical Work Periods," Behavioral Research Methods, Instruments, & Computers, 17(1):75-85, 1985.

Gambrell, B., Point Paper on Consideration of Circadian Rhythms in Operations Planning, XOXFC, Headquarters, U.S. Air Force, U.S. Department of the Air Force (Washington, DC, 1989).

Graber, J. G., Rollier, R. L., and Salter, J. A., Continuous Operations SOP for BIFV Units, U. S. Army Research Institute for the Behavioral and Social Sciences Field Unit, U. S. Army Research Institute for the Behavioral and Social Sciences, U. S. Department of the Army, USARI Research Note 86-60 (Fort Benning, GA: 1986).

Haslam, D. R., "Sleep Loss, Recovery Sleep, and Military Performance," Ergonomics, 25(2):163-178, 1982.

Hegge, F. W., The Future Battlefield: Human Dimensions and Implications for Doctrine and Research, Walter Reed Army Institute of Research, U. S. Army Medical Research and Development Command, U. S. Department of the Army, Report No. WRIAR NP-82-1 (Washington, DC: December, 1982)

Hegge, F. W., and Tyner, C. F., Deployment Threats to Rapid Deployment Forces, Walter Reed Army Institute of Research, U. S. Army Medical Research and

Development Command, U. S. Department of the Army, Report No. WRIAR NP-82-2 (Washington, DC: December, 1982)

Johnson, L. C., Freeman, C. R., Spinweber, C. L., *et al.*, The relationship between Subjective and Objective Measures of Sleepiness, Naval Health Research Center, Naval Medical Research and Development Command, U. S. Department of the Navy, NHRC Report No. 88-50 (San Diego, CA: December, 1988)

Kelly, T. L., Englund, C. E., Ryman, D. H., *et al.*, The Effects of 12 Hours of MOPP IV Gear on Cognitive Performance Under Non-Exercise Conditions, Naval Health Research Center, Naval Medical Research and Development Command, U. S. Department of the Navy, JWED3 Report No. 88-6 (San Diego, CA: 1987).

Kopstein, G., Siegel, A., Conn, J., *et al.*, Soldier Performance in Continuous Operations, prepared by Applied Psychological Services, Inc. for the U. S. Army Research Institute for the Behavioral and Social Sciences, U. S. Department of the Army, ARI Research Note 85-68 (Wayne, PA: July, 1985).

Krueger, G. P., "Sustained Work, Fatigue, Sleep Loss and Performance: a Review of the Issues," Work & Stress, 3(2):129-141, 1989.

Krueger, G. P., Armstrong, R. N., & Cisco, R. R., "Aviator Performance in Week-Long Extended Flight Operations in a Helicopter Simulator," Behavioral Research Methods, Instruments, & Computers, 17(1):68-74, 1985.

Krueger, G. P., Barnes, S. M., Human Performance in Continuous/Sustained Operations and the Demands of Extended Work/Rest Schedules: An Annotated Bibliography Volume II, u.s. Army Aeromedical Research Laboratory, U. S. Army Medical Research and Development Command, U. S. Department of the Army (Fort Rucker, AL: June, 1989).

Krueger, G. P., Cardenales-Ortiz, L., Loveless, C. A., Human Performance in Continuous/Sustained Operations and the Demands of Extended Work/Rest Schedules: An Annotated Bibliography, Walter Reed Army Institute of Research, U. S. Army Medical Research and Development Command, U. S. Department of the Army, USAARL report 79-1 (Washington, DC: May, 1985).

Mackie, R. R., Wylie, C. D., and Evans, S. M., "Fatigue Effects on Human Performance in Combat: A Literature Review," draft working paper prepared for the U. S. Army Institute for the Behavioral and Social Sciences, U. S. Army Medical Research and Development Command, U. S. Department of the Army, VRI-ARI-9 WP88-1, (Goleta, CA and Ann Arbor, MI: October, 1988).

Morgan, B. B., Brown, B. R., Coates, G. D., *et al.*, Sustaining Performance During 36 Hours of Continuous Work and Sleep, Performance Research Laboratory, University of Louisville, PRL Report ITR-75-31 (Louisville, KY: 1975).

Morgan, B. B., Coates, G. D., Sustained Performance and Recovery During Continuous Operations, Performance Assessment Laboratory, Old Dominion University, PAL Report ITR-74-2 (Norfolk, VA: 1974).

Naitoh, P., and Angus, R. G., Napping and Human Functioning During Prolonged Work, Naval Health Research Center, Naval Medical Research and Development Command, U. S. Department of the Navy, NHRC Report No. 87-21 (San Diego, CA: April, 1987)

Naitoh, P., Englund, C. E., and Ryman, D. H., Sustained Operations: Research Results, Naval Health Research Center, Naval Medical Research and Development Command, U. S. Department of the Navy, NHRC Report No. 87-17 (San Diego, CA: June, 1987)

Naitoh, P., Englund, C. E., and Ryman, D. H., Sleep Management in Sustained Operations User's Guide, Naval Health Research Center, Naval Medical Research and Development Command, U. S. Department of the Navy, NHRC Report No. 86-22 (San Diego, CA: July, 1986)

Neff, K. L., and Solick, R. E., Military Experts' Estimates of Continuous Operations Performance (Or Close But No Cigar), U. S. Army Research Institute for the Behavioral and Social Sciences, U. S. Department of the Army, USARI Report No. TR-600 (Alexandria, VA: 1983).

Poulton, E. C., The Effects of Fatigue Upon Sonar Detection, Royal Naval Personnel Research Committee, MRC NPRC Report No. OES 20-72 (London, England: 1972).

Rakoff, S. H., "Time to Reexamine Soldiers' Sleep Requirements," ARMY, December, 1987.

Rakoff, S. A., Marvin, F. F., & Govedich, M. M., TOE Nonavailability Factors Study: Final Study Report, Decision Science Consortium, Inc., Contract No. MDA903-85-C-0488 (Falls Church, VA: 1986).

Rosenthal, N. E., Seasons of the Mind: Why You Get the Winter Blues and What You Can Do About It, Bantam Books (New York, 1989).

Ryman, D. H., Naitoh, P., Englund, C. E., Perceived Exertion Under Conditions of Sustained Work and Sleep Loss, Naval Health Research Center, Naval Medical Research and Development Command, U. S. Department of the Navy, NHRC Report No. 87-9 (San Diego, CA: 1987)

Robeson, E. J., "Tactical Reflections on Norway," U. S. Naval Institute Proceedings, 115(11):108-111, 1989.

Siegel, A. I., Kopstein, F. F. Federman, P. J. *et al.*, Management of Stress in Army Operations, prepared by Applied Psychological Services, Inc. in collaboration with the U. S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, the U.S. Army Soldier Support Center, Fort Benjamin Harrison, IN, and the Walter

Reed Army Institute for Research, Washington, DC, U. S. Department of the Army, Research Product 81-19 (Wayne, PA: April, 1981).

Siegel, A. I., Taylor, S. E. Shuler, L. *et al.*, Human Performance in Continuous Operations - Guidelines, U. S. Army Research Institute for the Behavioral and Social Sciences, U. S. Department of the Army, USARI Report RP 79-8 (Alexandria, VA: 1983).

Spinweber, C. L., L-Tryptophan, Sleep and Performance, Naval Health Research Center, Naval Medical Research and Development Command, U. S. Department of the Navy, NHRC Report No. 87-17 (San Diego, CA: March, 1987)

Thompson, Henry L., "Sleep Loss and Its Effect in Combat," Military Review, September, 1983.

U. S. Department of the Army, Headquarters, U. S. Army Soldier Support Center, Soldier performance in continuous operations, Field Manual No. 22-9 (Washington, DC: 1983)

U. S. Department of the Navy, Military Planning and the Impact of Circadian Rhythms on Military Operations,

(briefing materials provided to Dr. Liskowsky of OTA, 1989) unattributed, undated.

Utterback, R. A., Ludwig, G. D., A Comparative Study of Schedules for Standing Watches Aboard Submarines Based on Body Temperature Cycles, Naval Medical Research Institute, U.S. Department of the Navy, NMRI Technical Report No. 1 (Bethesda, MD: 1949)

Vogel, J. A., Sampson, J. B., Wright, J. E. *et al.*, Effect of Transatlantic Troop Deployment on Physical Work Capacity and Work Performance, U.S. Army Research Institute of Environmental Medicine, U.S. Department of the Army, USARIEM Report T 3/79 (Natick, MA: 1979)

Word, L. E., Observations From Three Years at the National Training Center, U. S. Army Research Institute for the Behavioral and Social Sciences, U. S. Army Medical Research and Development Command, U. S. Department of the Army, ARI Research Product 87-02 (Alexandria, VA: 1987)

Department of Defense and Service Directives:

DoD Directive 5000.53, Manpower, Personnel and Training in System Acquisition.

U. S. Army Regulations:

AR 570-2, Manpower Requirements Criteria (MARC) - Tables of Organization and Equipment.

U.S. Navy Directives:

OPNAVINST 1000.16F, Manual of Navy Total Force Management.

OPNAVINST 3501.(series), Squadron Manning Document.

OPNAVINST 3710.7M, NATOPS General Flight and Operating Instructions.

U.S. Air Force Regulations:

AFR 28-40, Mobility for Tactical Air and Strategic Aerospace Defense Forces.

AFR 28-42, Mobility for Military Airlift Command Forces.

AFR 28-43, Mobility for SAC Forces in Contingency Operations.

AFR 60-1, Flight Management.

MACR 28-2, Contingency Planning Policies and Procedures.

MACR 55-1, Airlift Operations.

SACR 55-66, ICBM Operations.